Improvements to Tropical Cyclone Model Forecasts

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LONG-TERM GOALS

The long-term goal of this project is to investigate, develop, and implement the ability to analyze and predict tropical cyclone (TC) structure and intensity, and to reduce the occurrence of large-error track forecasts through the use of high-resolution numerical prediction systems and satellite observations.

OBJECTIVES

The objective is to improve TC initialization by the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS™[1]) through the use of synthetic observations and to improve COAMPS TC structure and intensity forecasts through the improvement of model numerics and physics.

APPROACH

Our approach is to enhance COAMPS to be a state-of-the-art high-resolution tropical cyclone forecast system suitable for operational TC intensity, structure and track forecast. The effort includes developing a tropical cyclone initialization system for COAMPS that uses the Navy Atmospheric Variational Data Assimilation System (NAVDAS) to analyze high-resolution synthetic observations for tropical cyclone initialization. The synthetic observations are constructed by fitting observed TC structure parameters to a modified Rankine vortex model. The observed TC structure parameters are obtained from warning messages issued by the Joint Typhoon Warning Center (JTWC) and from 34 kt and 50 kt wind radii retrieved from available satellite observations such as QuikSCAT. The effort also includes evaluating and upgrading COAMPS model physics to improve TC structure and intensity forecast. We evaluate and adopt numerical techniques such as two-way movable inner mesh, interactive nesting and dynamical initialization to look for further improvements to the TC structure and intensity forecast. We develop tools to internally track TC positions and objectively measure model performance in the TC structure and intensity forecast. We leverage other research programs at NRL that address satellite data processing, model numerics and physics, data assimilation, air-ocean and air-wave coupling, and validation to integrate the necessary technology into a complete high-resolution tropical cyclone prediction system.

[1] COAMPS™ is a trademark of the Naval Research Laboratory

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WORK COMPLETED

During FY02, we developed a method of enhancing COAMPS TC initialization by least square fitting the azimuthally averaged wind speed of QuikSCAT data to a fifth order polynomial to retrieve 34 kt and 50 kt wind radii of TCs. This year, we have completed the evaluation of the QuikSCAT enhancement for the COAMPS TC initialization. For a 3-month period from 8 July to 8 October 2002, we compared all 34 kt and 50 kt wind radii objectively retrieved from operationally available QuikSCAT observations with those available from the JTWC warning messages. We also compared 48h track and structure forecast of 36 cases selected from 5 TCs that are initialized with and without the QuikSCAT retrievals.

We completed development of an internal TC tracker software package for COAMPS that can determine TC circulation centers and extract intensity and structure parameters of all active TCs during the model forecast. The internal tracker first estimates the possible locations of TC circulation centers by identifying nearby pairs of vorticity maximum and sea-level pressure minimum centers. Point by point search for cyclonic centers is then conducted around those possible locations to pin point TC circulation centers. Some empirical criteria are set for the vorticity maximum and sea-level pressure minimum to avoid mistreating extra tropical cyclones as tropical cyclones. Once the TC center has been located, the maximum wind speed is determined by searching for the maximum wind speed at the lowest model level (10 m above the ground) around the TC center. Azimuthally averaged wind speed at 4 quadrants is computed in every 4 km and then an inward search from the TC edge at each quadrant toward the TC center is conducted to determine the 34kt and 50kt radii of the TC at each quadrant.

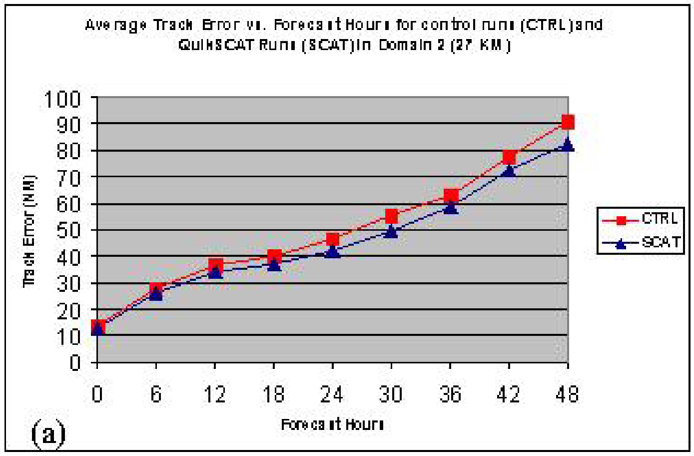
We completed the evaluation of spatially varying background error correlation in COAMPS tropical cyclone analysis. Since the 3D-Var analysis NAVDAS is not available yet, we mimic this feature by modifying OI analysis with 2 analysis cycles. In the first analysis cycle, regular COAMPS OI analysis is used but without reading in TC bogus data. In the second analysis cycle, the OI analysis uses a background error correlation function with a smaller horizontal scale and the analysis reads the TC bogus data only. Therefore, the second analysis cycle is equivalent to apply a smaller scale error correlation function for the OI analysis near the TC center. We have evaluated the 2-cycle OI analysis with several different horizontal scales for 45/15/5 km grid resolution TC analysis.

We finished the evaluation of a new microphysics parameterization for COAMPS TC track, intensity and structure forecast. The new microphysics developed by NRL scientists funded by a NRL base program includes more completed microphysics processes and a better consistent moisture conversion calculation that ensures the energy and mass conservation. We have conducted 11 COAMPS 48h forecasts of 6 TCs selected from the 2002 season with 45/15/5 km nests, in which the 5km mesh is moving with a selected TC. For one case, Lili at 2002100200, we examined in details the intensity, precipitation and cloud physics parameters simulated by the original and new microphysics parameterization. This evaluation helps the decision to replace the original microphysics parameterization by the new microphysics parameterization for COAMPS operation at FNMOC.

RESULTS

In the 3-month period of evaluating the impact of QuikSCAT data on COAMPS TC initialization, there is 28% chance that QuikSCAT data are available near active TCs. The mean difference between the objectively retrieved 34 kt wind radii and those in the JTWC warning messages is about -8 nautical miles (NM), and the root-mean-square (RMS) difference between the two is 45 NM. The mean and

RMS difference for the 50 kt wind radii are 16 NM and 42 NM, respectively. Since a typical 34 kt wind radius is about 150 NM to 200 NM, the -8 NM mean difference and 45 NM RMS difference indicate that the objectively retrieved 34 kt wind radius generally agree with the values in the warning messages. However, a typical 50 kt wind radius is about 50 NM to 100 NM, the 16 NM mean difference and 42 NM RMS difference are quite significant. From the evaluation of individual cases, we find that the objectively retrieved 50 kt wind radii are more consistent with the available 34 kt wind radii. In the 36 cases of 48h forecast, the QuikSCAT data enhancement gives minor improvement to the track forecast but rather significant improvement to the wind structure forecast (Fig. 1).



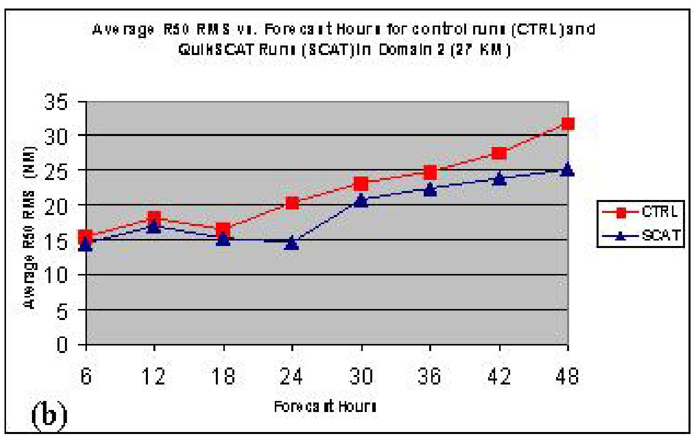


Figure 1. Comparison of 36 TC (a) track and (b) 50kt wind radius forecasts by COAMPS 27 km mesh for the TC initialization without (red box) and with (blue triangle) QuikSCAT enhancement.

Examples of the internal TC tracker output for a case that has two active tropical cyclones inside the model domain are shown in Tables 1 and 2. A one hour tracking interval is selected for these examples. These two files are combined and reformatted at the end of COAMPS forecast to fit to the input format of ATCF. This internal TC tracker has been tested for more than 200 cases and it works well in all cases.

We have tested the reduction of the OI background error correlation horizontal scale in the second analysis cycle by 1.5 to 3 times smaller for the 15 km mesh and 2.0 to 4 times smaller for the 5 km mesh. The results show that the smaller horizontal scale has a larger impact on the wind analysis, but

less impact on the height analysis. A small horizontal scale generally gives a deeper and stronger TC circulation analysis. However, too small of a horizontal scale will give a noisier but not much deeper TC analysis. The best TC analysis for the 15 km mesh is obtained with a horizontal scale of 210 km, and the best one for the 5 km mesh is about 160 km. Figure 2 shows the comparison of 15 km sea-level pressure and 850 mb wind analysis of hurricane Lili at 2002100212 between regular OI analysis with 375 km horizontal scale and the 2-cycle OI analysis with 210 km horizontal scale in the second cycle. The central sea-level pressure difference between the two analyses is about 3 mb, while the maximum wind speed difference is about 10 kt with sharper wind gradient shown in the 2-cycle analysis.

We have tested and evaluated the new microphysics for 11 COAMPS™ 48h forecasts of 6 tropical cyclones: Edouard, Isidore, Lili, Phanfone, Rusa, and Sinlaku. The new microphysics has both positive and negative, but rather limited, impact on track forecast for all meshes. However, it cures the intensity underprediction problem of the high-resolution mesh. An example for hurricane Lili is shown in table 3. In comparing the microphysics parameters simulated by the original and new microphysics, we found that the major difference between the two is due to the lack of grauple in the original microphysics parameterization.

Tau	**Lat**	**Lon**	**dir**	**spd(m/s)**	**slp(mb)**	**Lat**	**Lon**	**dir**	**spd(m/s)**	**slp(mb)**
0.0:	22.87	274.24	0.00	0.00	992.26;	28.30	292.40	0.00	0.00	1009.61;
1.0:	22.94	274.09	301.70	9.43	989.98;	28.22	292.39	181.58	4.62	1008.35;
2.0:	23.05	273.88	304.90	13.23	993.22;	28.21	292.27	257.09	6.12	1007.71;
3.0:	23.11	273.64	288.35	13.78	994.80;	28.27	292.17	293.28	6.14	1008.58;
4.0:	23.21	273.37	295.96	15.96	995.84;	28.37	292.12	326.88	7.11	1009.43;
5.0:	23.31	273.09	296.26	16.87	995.68;	28.50	292.10	343.91	7.51	1009.41;
6.0:	23.45	272.80	301.50	18.09	996.42;	28.58	292.09	350.95	4.83	1009.44;

Table 1. Example of internal TC tracker output of TC locations and central sea-level pressure for two active TCs in every hours of a COAMPS 6h forecast.

Tau	**R34(km)**				**R50(km)**				**vmax(m/s)**	**R34(km)**				**R50(km)**				**vmax(m/s)**
0.0:	284	212	148	196	196	152	0	128	36.3;	0	0	0	0	0	0	0	0	16.6;
1.0:	252	172	132	172	136	0	0	0	27.7;	0	0	0	0	0	0	0	0	14.4;
2.0:	252	176	116	172	136	0	0	0	27.1;	0	0	0	0	0	0	0	0	14.6;
3.0:	272	184	0	188	0	0	0	0	27.3;	0	0	0	0	0	0	0	0	14.5;
4.0:	288	180	0	196	0	0	0	0	26.0;	0	0	0	0	0	0	0	0	13.9;
5.0:	304	168	0	184	0	0	0	0	25.1;	0	0	0	0	0	0	0	0	13.6;
6.0:	304	168	0	172	0	0	0	0	25.3;	0	0	0	0	0	0	0	0	13.7;

Table 2. Example of internal TC tracker output of 34 kt and 50 kt wind Radii (km) at 4 quadrants and maximum wind speed (m/s) for two TCs in every hours of a COAMPS 6h forecast.

IMPACT/APPLICATIONS

Objectively retrieved 34 kt wind radii from QuikSCAT data are similar to those in the JTWC warning messages. However, the retrieved 50kt wind radii are significantly larger then those in the warning messages and more consistent with the 34 kt wind radii. The QuikSCAT data enhancement also leads to better 50 kt wind radius forecast. Horizontal scale of background error correlation for OI analysis

has larger impact on the TC wind analysis and less impact on the TC height and sea-level pressure analysis. Microphysics parameterization has limited impact on TC track forecast for any resolution grids, while it significantly influences the TC intensity forecast of high-resolution grids.

FORECAST	MSLP (HPA)			MAXWND			TRACK ERROR	
0	987	987	967	46	50	90	4	4
6	985	977	954	65	74	100	8	3
12	989	969	954	52	75	110	12	14
24	993	965	940	49	80	125	57	48
36	995	968	962	38	73	80	116	84
48	997	965	985	40	63	40	166	134

Table 3. Comparison of COAMPS 48h forecast of central sea-level pressure, maximum wind, and track errors for 5 km moving mesh between original microphysics (red in first column), new microphysics (blue in second column) and observation (black in third column).

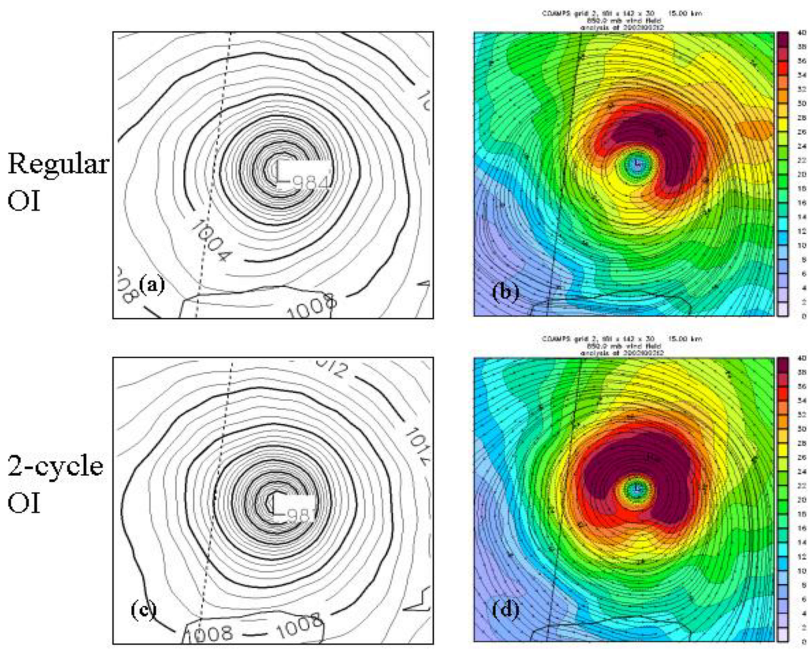


Figure 2. Comparison of 15 km TC analysis of (a), (c) sea-level pressure and (b), (d) 850mb wind between regular and 2-cycle OI analysis, respectively.

TRANSITIONS

The internal TC tracker developed for COAMPS and the associated routines to output TC intensity and structure forecast were delivered to FNMOC in August 2003. The package dynamically tracks all active TC circulation centers in the COAMPS grid domains without first guesses so that it can detect TC genesis. The associated routines output TC forecast of position, maximum wind, central sea-level pressure, and radii of 34kt and 50kt at 4 quadrants every 6 hours to a file for ATCF input.

RELATED PROJECTS

Related 6.2 projects within PE 0602435N are *High Resolution Mesoscale Model Prediction and Validation* funded by ONR, and the NRL base program BE-35-2-32 *Satellite/NWP Data Fusion for Weather Assessment;* and a related 6.4 project as part of this RTP is under PE 0603207N *Tropical Cyclone Forecast Systems*.

PUBLICATIONS

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